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ELECTROCHEMICAL BEHAVIOR OF SURGICAL ALLOYS, (U)
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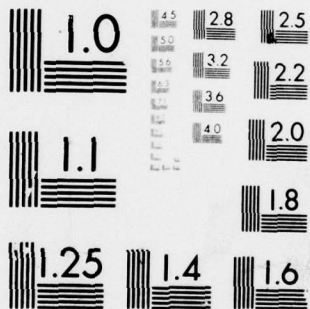
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ELECTROCHEMICAL BEHAVIOR OF SURGICAL ALLOYS

The usefulness of certain chromium-containing alloys for the fabrication of orthopedic, maxillofacial and dental implants is based largely upon their alleged ability to resist corrosion. Although the rate of interaction of these materials with the physiologic environment may be relatively slow, their dissolution (corrosion) does occur.¹⁻⁷

Implant applications of chromium-type alloys require consideration of the probability of the occurrence of (1) galvanic interaction of dissimilar metals,⁸ (2) stress corrosion⁹ and (3) crevice corrosion.¹⁰ The effects of galvanic interaction can be minimized by insuring that all portions of multiple component prostheses be fabricated from the same alloy. For the most part, yield assisted (stress) corrosion can be precluded by selection of alloys exhibiting suitable mechanical properties and by the application of rational engineering principles in the design of implant prostheses. Unfortunately, the juxtapositional relationship of a metallic implant to soft and hard tissues creates crevices which encourage electrochemical attack (crevice corrosion). Structural weakening and adverse tissue response are possible manifestations of the prolonged dissolution of an implant by crevice corrosion.

The present investigation was conducted to study the electrochemical behavior of three biomedical alloys and to determine their relative susceptibilities to crevice corrosion in a chloride medium.

Materials and Methods

Specimens for in-vitro testing were fabricated from each of two surgical grade base metal casting alloys (Vitallium^{*} and Ticonium⁺) and from a proprietary low carbon stainless steel orthopedic pin.[#] Rods (4.0 mm X 8.0 mm) were cast from Vitallium and Ticonium through the use of conventional lost-wax dental laboratory procedures. Segments (4.0 mm X 8.0 mm) were cut from the cylindrical shank of the pre-fabricated bone pin.

The planar test surface of each specimen was polished manually on 600 grit metallurgical paper, cleansed in detergent and rinsed with alcohol. Each metallic piece was force-fitted into a Teflon fixture (Figure 1). The metal-Teflon juncture created an interface of miniscule width which simulated a circumferential implant-tissue crevice. Additionally, the assembly provided a means for establishment of a stable electrical connection.

Cyclic polarization of the alloys was accomplished in lactated Ringer's solution[§] (chloride ion concentration 109 m Eq per liter).

* Cobalt (~60%), chromium (~30%) and molybdenum (~4%) alloy.

Howmet Corp., Chicago, IL.

+ Nickel (~54%), chromium (~25%) and cobalt (~15%) alloy.

CMP Industries, Albany, NY.

Steinmann Bone Pin. The device was obtained through the medical supply system of the uniformed services.

§ Cutter Laboratories, Inc., Berkeley, CA.

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Temperature of the medium was maintained at 37°C. The polarization cycle was initiated at a potential of about -1.0 V versus a saturated calomel electrode (SCE). The potential of each specimen (working electrode) was made increasingly anodic at a rate of 0.010 V/sec with the use of a programmable potentiostat.^Ω The anodic change in potential was allowed to progress until a maximum current density of $1 \times 10^3 \mu\text{A}/\text{cm}^2$ was experienced by the working electrode. Then the direction of change of the applied potential was reversed. Completion of the polarization cycle was marked by the return of the externally applied potential to a value of about -1.0 V versus SCE.

Output of the potentiostat was monitored continuously on a Cartesian coordinate recorder.[¶] Graphic displays of changing current density with impressed potential produced anodic and cathodic potentiodynamic polarization diagrams which reflected the electrochemical behavior of the test substances in the simulated physiologic environment.

Results

Cyclic potentiodynamic polarization diagrams for surgical stainless steel, Vitallium and Ticonium are presented in Figures 2-4, respectively. The anodic portions of these diagrams depicted transition from a cathodically protected metastable condition to a reactive

^Ω Universal Programmer, Model 175, Analytical Instrument Division, Princeton Applied Research Corp., Princeton, NJ.

[¶] X-Y Recorder, Model 9002A, Analytical Instrument Division, Princeton Applied Research Corp., Princeton, NJ.

state and subsequently delineated the active,^a passive^b and trans-passive^c ranges of the alloys. Corrosion potential^d was marked by intersection of the anodic (oxidation) and cathodic (reduction) curves.

The behavior of the test materials became predominantly anodic at potentials which ranged from -0.575 V for Vitallium to -0.300 V for stainless steel. The active linear ranges of the alloys were relatively short. The corrosion potentials and breakdown potentials of the three implant materials were remarkable similar. Stainless steel exhibited the highest passive current density.

An additional relationship of the paired curves contributed information relevant to the electrochemical behavior of the alloys. The diagram produced on cyclic polarization of the low carbon steel (Figure 2) revealed a distinct hysteresis between its anodic and cathodic components. On the other hand, the diagrams for Vitallium (Figure 3) and Ticonium (Figure 4) exhibited little or no hysteresis.

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- a Marked increase in current density with little or no change of impressed anodic potential.
 - b Little or no change in current density with the increase of impressed anodic potential.
 - c Breakdown of passivity.
 - d Potential at which oxidation and reduction of an alloy occur at equal rates.

Discussion

Understandably, a functional surgical prostheses is not subjected to externally controlled polarization. However, an appreciation of impressed potential-current density relationships is essential to the rational clinical application of metallic implants.

Any alloy exposed to a corrosive medium will, in time, spontaneously reach its so-called equilibrium (corrosion) potential. The degree of activity or passivity exhibited by an alloy at equilibrium with its environment is governed by compositional and structural features of the alloy and by the oxidizing power of the environment. Ideally, an active-passive biomedical alloy should passivate spontaneously when exposed to extracellular fluid or to a synthetic medium of comparable chloride ion concentration.

Under simulated physiologic conditions the passivating tendency of stainless steel, Vitallium and Ticonium is weak. Furthermore, at their corrosion potentials, the behavior of the three alloys is active rather than passive. The findings infer that in vivo passivation of implants fabricated from these materials may not occur. Failure of a metallic implant to passivate would, undoubtedly, result in the continuous release of metallic ions to the adjacent tissues and their subsequent transport to distant target organs.

The hysteresis displayed by the cyclic polarization curve of surgical grade stainless steel merits careful attention. Industrial chromium-containing alloys that exhibit a similar hysteretic tendency on cyclic polarization have been shown to be highly susceptible to

crevice corrosion.¹¹ The likelihood of the prolonged dissolution of stainless steel at the implant-tissue phase boundary crevice should be considered in all implant applications of this material.

Summary

The electrochemical behavior of three surgical alloys was studied. In a simulated physiologic environment, the active-passive transition of the test materials was weak. At their respective equilibrium potentials the behavior of stainless steel, Vitallium and Ticonium was characterized by active dissolution. The low carbon ferrous alloy appeared to be more susceptible to the detrimental effects of crevice corrosion than either Vitallium or Ticonium.

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Legends for Figures

Figure 1. Assembly employed in cyclic polarization of surgical alloys.

Figure 2. Cyclic potentiodynamic polarization diagram for surgical stainless steel.

Figure 3. Cyclic potentiodynamic polarization diagram for Vitallium.

Figure 4. Cyclic potentiodynamic polarization diagram for Ticonium.

A-A SECTION

